

Contributions to the Mineralogy of Western Australia
 by **Edward S. Simpson**, D.Sc., B.E., A.A.C.I.

Series 1.

(Read April 13, 1926. Published May 6, 1926.)

Contents:

	Page
(1). Lithiophilite, Wodgina.	57
(2). Leucite, Fitzroy Valley.	58
(3). Ferrimolybdite, Mulgine.	59
(4). Kyanite, Chittering Valley;	62
(a) Lower Chittering;	62
(b) South Bindoon;	63
(c) Wattle Flat, Cullalla.	64
(5). Staurolite, Cullalla.	65
Genesis of the Chittering Kyanite and Staurolite	66

(1). *Lithiophilite, Wodgina, N.W. Div.*

This very rare phosphate of lithium and manganese has previously been recorded from only three districts in the world, all in the United States, viz., in Maine, North Carolina and California.

A single detrital boulder of this mineral, over a kilogram in weight, has been received in Perth from a locality said to be about 20 miles south west of Wodgina (Lat. 21-22° S., Long. 118-119° E.). On the surface of the specimen there is a thick (1 to 2 cm.) crust of mixed limonite and psilomelane evidently pseudomorphous after the lithiophilite. Beneath is the unweathered mineral composed of two crystal individuals traceable by the well defined, but far from perfect, basal cleavage. Indications of the prismatic cleavages b (010) and m (110) are also to be seen. The mineral is translucent in slices 1 mm. thick, possesses a resinous lustre, and a color in mass which is slightly variable, ranging from almost colorless

to about Ridgways 19'k (buffy citrine) and 21'i (olive lake). The powder is nearly pure white, and under the microscope is transparent and colorless, with the lowest refractive index slightly above 1.660, and with moderate birefringence. Its density is 3.39 and hardness 5.

In a closed tube the mineral decrepitates slightly, gives off water and darkens in color. Before the blowpipe it fuses rather readily to a black slag.

The powder moistened with strong sulphuric acid does not etch glass, but gives a strong lithium flame. Ground fine the mineral dissolves rather slowly in cold dilute (5E) HNO_3 , HCl or H_2SO_4 , but rapidly in all three when warmed. An analysis of carefully selected material showed the presence of 0.06 per cent. moisture and 0.72 insoluble matter of which 0.58 was silica. Deducting these impurities the results obtained were:

P_2O_5 .	MnO.	FeO.	CaO.	MgO.	Li_2O .	Na_2O .	K_2O .	$\text{H}_2\text{O}+$	Total.
45.99	30.80	10.44	2.78	0.94	7.87	0.34	nil	1.11	100.27

A duplicate determination of the Li_2O by another analyst gave 7.88 per cent. The corrected density of the analysed material was 3.39. The analytical figures yield ratios: $\text{P}_2\text{O}_5:(\text{Mn,Fe})\text{O}:(\text{Li,H})_2\text{O}$ of 0.990:1.995:1.012, theory requiring 1:2:1.

Other than the products of its own decomposition the only foreign mineral visible in the specimen was quartz in small amount. It would appear as if the boulder were shed from a pegmatite vein.

The only other phosphate known in the district is apatite, which occurs in large masses up to several kilos in weight.

(2). *Leucite, Fitzroy Valley, Kim. Div.*

A number of small plugs of a volcanic agglomerate rich in leucite have been discovered by Messrs. T. Blatchford and H. W. B. Talbot in the middle Fitzroy valley where they rise through upper Carboniferous sandstones and shale in the form of small hills along a line running north 65° west. The easternmost dome is at Survey station C.48 on Christmas Crk. (Lat. $18^\circ 41'$ S., Long. $125^\circ 37'$ E.), the westernmost at "B.E." Hill (Lat. $17^\circ 57'$ S., Long. $124^\circ 19'$ E.), 13 miles N.W. of Mt. Wynne, the distance between the two being 100 miles. Mr. J. E. Wells has also discovered an isolated neck of the same rock at Mt. North (Lat. $17^\circ 29'$ S., Long. $124^\circ 49'$ E.), 45 miles N.E. of B.E. hill. The rocks have been very briefly referred to by R. A. Farquharson

in the Annual Reports of the Geological Survey for 1919* and 1921†, but no published description is available.

The rocks are dark green to pale grey in color, and characteristically dotted with small flakes of red brown biotite. An agglomeratic structure is often distinctly visible.

An analysis was made of a specimen from Barjar Hill near Noonkanbah homestead with the following results:

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O		
52.45	8.64	5.48	.94	.13	6.42	2.01	.38	10.42		
H ₂ O—	H ₂ O+	TiO ₂	CO ₂	P ₂ O ₅	FeS ₂	SO ₂	BaO	Total	D	
1.99	2.89	5.85	nil	1.58	nil	nil	1.19	100.37	2.60	

Analyst, D. G. Murray.

The high percentages of titanium and barium are remarkable. Washington, however, records a leucitite from Bearpaw Peak, Montana, with 0.50 per cent of BaO. A thin section of this rock reveals the fact that idiomorphic leucite is the most abundant constituent. The rounded or octagonal crystals vary from 0.03 to 0.50 mm. in diameter, and the larger ones show numerous dusty inclusions arranged either concentrically or radially. Between crossed nicols the larger crystals are flecked with small areas which are faintly birefringent.

The associated minerals are finely divided chlorite, innumerable small needles of rutile, small prisms of apatite and irregularly scattered flakes of biotite larger than the largest leucite.

In the rock from "B.E." Hill, the leucite is not so plentiful, and is in larger grains up to 1mm. in diameter, and the inclusions are not so regularly arranged. There is more biotite present, and a considerable proportion of a titaniferous augite, with yellow to violet pleochroism. In this rock, too, the larger augite and biotite individuals usually enclose several crystals of leucite.

This is the only district in West Australia from which leucite has been recorded.

(3). *Ferrimolybdite, Mulgine, S.W. Div.*

Ferrimolybdite is preferable to molybdite as a name for the natural hydrated molybdate of iron, as most text-books give entirely misleading descriptions of "molybdite" based not on the

* A.R.G.S.W.A., 1919, p. 42. According to J. E. Wells the locality given as Mt. Eliza should be Mt. North. This rock contains K₂O, 7.50 per cent.; Na₂O, 0.68 per cent.

† A.R.G.S.W.A., 1921, p. 56.

natural mineral, but upon artificial molybdic oxide, with which it was for long quite erroneously assumed to be identical.

As first noted by A. Gibb Maitland and the author in 1917*, excellent specimens of this mineral in a great state of purity have been found from time to time in the upper workings on the molybdenite deposits of Mt. Mulgine (Lat 29° S., Long. 117° E.). The mineral occurs in joints or small cavities in granite greisen or pegmatite, in some cases being plainly pseudomorphous after molybdenite. The masses are all distinctly fibrous, even when still preserving the broad foliation of the original molybdenite. They are very friable, and therefore difficult to collect and handle, passing soon into a microscopically fibrous powder, the individual fibres having a diameter of 2 to 8 microns with lengths up to 1 mm.

As some doubt has existed regarding the composition of the mineral, more particularly in regard to its water content, an analysis was made of carefully selected material taken from the largest single mass obtained, which weighed nearly 2 grammes. A very small quantity of associated quartz was removed with methylene iodide, and after thorough washing in the cold with xylol, alcohol and ether in succession, it was kept under loose cover sufficiently long to be sure of its having reached equilibrium under prevailing cool dry atmospheric conditions. Analyses were made of two separate lots at intervals of some days, the results being as follow:—

Lot	<i>Ferrimolybdite, Mulgine.</i>				Theory (Simpson) per cent.
	per cent.	A mols.	B per cent.	mols.	
Ferric oxide, Fe ₂ O ₃	17.87	112	18.29	115	17.44
Molybdic oxide, MoO ₃	62.90	437	(62.46)	434	62.90
Water over CaCl ₂	10.20	566	} 19.25	1069	9.83
Water at 250° ..	9.95	552			
	<hr/> 100.92 <hr/>		<hr/> 100.00 <hr/>		<hr/> 100.00 <hr/>

The appreciable difference in water percentage between the two analyses of the one well-mixed mass of material, as well as the variable and often quite low proportions of water noted by Schaller and others† were explained by experiments made to determine the temperature and rate at which the mineral loses

* A.R.G.S.W.A., 1916, p. 10, 25.

† U.S.G.S. Bull. 490, pp. 84-92.

its water. This constituent was found to be very readily lost as the following figures show:—

Dehydration of Mulgine Ferrimolybdate.

	Total time.		Colours.	
	hours.	Water loss per cent. Individual Total		
Stage I.				
In balance	2	1.87	1.87	Picric yellow
case with	3	.50	2.37	
CaCl ₂	6	1.33	3.70	
	12	2.12	5.82	
	100	2.93	8.75	
	365	1.37	10.12	
	440	.08	10.20	Deeper yellow
Stage II.				
Steam oven	2	.52	10.72	
at 100°	8	.38	11.10	
	11	nil	11.10	Dark yellow
Stage III.				
Air oven	1	1.50	12.60	
at 125°	2	.65	13.25	
	4	.72	13.97	
	12	3.48	16.45	
	14	.05	16.50	Yellowish green
Stage IV.				
Air oven	1	3.15	19.65	
at 200°	3½	.22	19.87	
	5	.05	19.92	Olive green
Stage V.				
Air oven	1	.23	20.15	
at 250°	3	nil	20.15	Olive green

Very many intermediate weighings were made which are not shown in the table. Almost identical figures to those shown under Stage I. were obtained when the mineral was desiccated over sulphuric acid.

It is evident that ferrimolybdate is very susceptible to desiccation, a fact which explains the lower water percentage in B, after keeping a few days in the warmer atmosphere of the laboratory. It also explains the lower and variable ratios for H₂O to MoO₃ given for the artificial compounds and for the minerals from American localities given by Schaller. The colour changes during drying were most marked, and have previously been noted by Schaller in the mineral from American localities.

The ratio of Fe_2O_3 to MoO_3 for the unusually clean Mulgine mineral is (A) 1:3.90. This is close to the ratio 1:4 given for the artificial compound. Schaller's ratios are nearer 1:3, but his material may have contained limonite, which is a frequent associate.

The formula for ferrimolybdate drawn from these figures is $\text{Fe}_2\text{O}_3 \cdot 4\text{MoO}_3 \cdot 5\text{H}_2\text{O} + 5\text{H}_2\text{O}$. This differs somewhat from previous suggestions ($\text{Fe}_2\text{O}_3 \cdot 3\text{MoO}_3 \cdot 7\frac{1}{2}\text{H}_2\text{O}$, Schaller).

The Mulgine mineral is insoluble in water, but is readily dissolved by warm hydrochloric acid, and slowly decomposed by warm ammonia water, MoO_3 going into solution and the iron being converted into ferric hydroxide. Remembering that ferrimolybdate is an acid salt, these facts point to the genesis of the mineral in weakly acid ferruginous waters resulting from the simultaneous weathering of pyrite and molybdenite. Secondary powellite on the other hand results from the weathering of molybdenite in the presence of alkaline calcareous waters.

The physical properties of the Mulgine mineral are as follow:—Density, 2.99. This agrees with Schaller's figure for the mineral from Hortense, Colorado. Hardness, small but indeterminate owing to the extreme fineness of the fibres and their almost complete lack of cohesion. The colour in mass is identical with Ridgways 23 d, picric yellow. Under the microscope the fibres are perfectly transparent and of a pale yellow colour at right angles to the elongation. Parallel to it the absorption is very marked, the thicker fibres being dark yellowish green and almost opaque, the thinner ones a lighter green.

After partial dehydration to a light green colour caused inadvertently by mounting in hot balsam, the absorption parallel to the fibres is complete in thicker fibres, which appear quite black, changing to yellowish green across the fibres. The marked pleochroism is referred to by Lacroix in describing the mineral from Corsica, and by Schaller in describing the United States specimens. The extinction is in all cases parallel, and the birefringence high, with Z parallel to the elongation.

(4) *Kyanite, Chittering Valley, S.W. Div.*

Kyanite has been found in several places in the gneissic granite ranges north of the junction of the Chittering Brook and the Swan River. The three occurrences here described all lie between Lat. 31° and 32° S, and a little east of Long. 116° E.

Lower Chittering.—The first known occurrence is on the south side of a small valley tributary to the Chittering Valley east of

Loc. 818. Close to the main valley the rock is massive granite, which becomes more gneissic as one goes east until at the kyanite locality (about $1\frac{1}{4}$ miles east of Loc. 818) the rock is highly foliated and micaceous. Occasional dykes of epidiorite and veins of quartz are seen running north, parallel to the foliation of the rock. Where the kyanite is found the outcrops are considerably obscured by soil, but the observations made show that all the mineral occurs in a large quartz vein probably forming a contact between gneiss and somewhat platy epidiorite. It is apparently confined to quite a small section of the vein, as specimens could only be found over an area of a few square yards. Within this area, however, magnificent specimens can be obtained of white quartz thickly studded with large tabular crystals of kyanite. At the surface this is grey blue in colour and often rather heavily iron-stained. Where protected, however, it is translucent with a colour ranging from orient blue through Alice blue to sky grey (Ridgway, 45" to 45" f), rarely sky blue (47'd) or Yale blue (47'b). The tint quite frequently varies in different parts of the one crystal. The crystals vary in size from 5 x 2 x 1 mm. to 70 x 20 x 5 mm., the larger sizes being more plentiful. A single crystal collected in the vicinity by A. King (a local resident) reaches 80 x 30 x 15 mm. Often the crystals are curved or bent. They occur singly in the quartz or in large confused groups of many individuals. Fine scaly muscovite or biotite in very small amount is the only mineral associated with them in the quartz. The forms commonly seen are (100), (010) and (001); (011) appears in traces on one or two crystals. The typical cleavages and basal parting are everywhere conspicuous. No twinning can be recognised in hand specimens.

South Bindoon.—E. de C. Clarke was the first to find kyanite in 1925 on a northerly spur of Red Hill, about $\frac{3}{4}$ mile east of the school reserve and near the south-east corner of Loc. 1363. The mineral is abundant over several acres of outcrop of what appears to be a granite gneiss. The main rock is traversed by an epidiorite dyke and by many thin lenticular quartz veins which are parallel to the foliation. That severe metamorphism has gone on in the locality is indicated not only by the development of secondary kyanite, muscovite and biotite, but by intense local folding over small areas. Two detrital boulders of vein quartz were picked up showing embedded kyanite in white and iron-stained crystals up to 45 x 20 x 5 mm., the specimens being reminiscent of the Lower Chittering occurrence. None was found, however, in situ in any of the many small quartz veins, but in many places smaller kyanite crystals are plentiful in this biotitic layers of the rock in contact with the veins. The typical occurrence, however, is in long narrow lenses of the gneiss parallel to the foliation. These

frequently occurring lenses are often many metres in length, but seldom exceed 30 cm. in thickness. They are usually characterised by abundant dark mica and numberless long-bladed crystals of kyanite lying at various angles closely parallel to the foliation, and showing out prominently on weathered surfaces. The proportion of kyanite in a specimen from a typical lens was found by crushing and floating in methylene iodide to be 15 per cent. In colour the mineral is white, pale grey or somewhat iron-stained. The smallest visible crystals measure about $5 \times 1 \times \frac{1}{2}$ mm., the largest $70 \times 5 \times 3$ mm., a very common size is $20 \times 2 \times 1$ mm. Under the microscope in fine grains they are seen to be colourless, with the typical cleavages, extinction angle, and refractive indices.

Wattle Flat (Cullalla).—Eight miles north of the South Bindoon occurrence, and almost on the same line of strike, the writer recently found a kyanite-bearing schist in a hill on the west side of Wattle Flat, almost at the extreme head of the Chittering Brook, here called the Brockman River. This place is near the N.W. corner of Loc. 805, three miles N.E. of Cullalla railway station.

The rock is a coarse-grained biotite schist interbedded with other more or less highly altered rocks of a gneissic character, and striking approximately north. The kyanite was found in two forms. First as distinct white or pale grey crystals, varying in size from $10 \times 4 \times 3$ mm. to $60 \times 15 \times 10$ mm., and having surfaces indented by crystals of biotite. Some of these crystals are solid kyanite and have the full density of 3.60, others have a lower density down to 3.35, apparently due to inclusion of quartz and mica. Some crystals show evidence of repeated twinning on (001). Quartz veins are small and rare, and in only one case was kyanite found associated with one. In this case large dense crystals were attached to the outside of the vein and included in a biotite parting in the vein.

The second mode of occurrence is really a modification of the first. A number of granular white lenticular "eyes," which were conspicuous in the schist, were found on examination to consist of a mixture of quartz and kyanite, the former preponderating. A typical one weighing five grammes was crushed and separated with methylene iodide. The returns were 60 per cent of quartz with typical optical properties and a density under 2.67*, and 38 per cent of kyanite with density over 3.32 and of characteristic appearance under the microscope. The small remainder was biotite. A close examination of these "eyes" usually discloses a Fontainebleau structure, the predominant granular quartz being

* The whole fraction under 2.67 contained over 96 per cent. of silica. The fraction over 3.32 contained 43 per cent. of silica and 56 per cent. of alumina, indicating the presence of 89 per cent. of kyanite, with 10 per cent. of included quartz.

enveloped by a single crystal individual of kyanite, whose continuity over the whole "eye" can be traced by reflection from a cleavage face.

(5) *Staurolite, Cullalla.*

In 1920, in describing staurolite from Mogumber, the writer referred to specimens of the mineral having reached Perth from an indefinite locality about 13 miles N.E. of Gingin.* Wattle Flat, referred to above is 12 miles N.E. of Gingin, and at this point Mr. de Courcy Clarke and the writer discovered a loose boulder of staurolite schist early in 1926. A further search by Mr. Bowley and myself resulted in the discovery of the outcrop of this rock within a few yards of the kyanite schist described above.

The staurolite schist occurs on the crest of a ridge on the west side of Wattle Flat close to the north end of Loc, 805. It forms an approximately vertical band several feet wide in a series of gneisses and schists, including gneissic microcline-hornblende granite, quartz-kyanite-biotite schist, quartz-garnet-biotite gneiss and gneissic epidiorite. The staurolite rock appears at first sight to be a highly ferromagnesian rock, the comparatively large flakes of black biotite enveloping and concealing all the other constituents except the large "eyes" of staurolite. A section of the rock, however, reveals its constituents in approximate order of abundance to be (1) quartz, (2) staurolite, (3) biotite, (4) hornblende, (5) muscovite, (6) chlorite, (7) felspar, (8) iron ore, (9) zircon. There is no indication of the quartz ever having been water worn.

A partial analysis shows that the fresh rock as a whole carries 73 per cent. of silica, and 13 per cent. of alumina. These are the proportions present in typical Darling Range granite, e.g., at Mahogany Creek (SiO_2 , 73; Al_2O_3 , 14), and Bannister (SiO_2 , 72; Al_2O_3 , 12.5). The iron in the staurolite schist appears, however, to be higher and the lime lower than in these granites. The only other staurolite schists whose analyses are on record differ greatly from this in their low silica percentages, 40.8 in one from Mogumber analysed by the author, and 41.5 in one from Switzerland quoted by Grubenmann.†

The staurolite occurs as abundant "eyes" in the schist, which are very prominent on exposed surfaces, and round which the scales of biotite and muscovite sweep in graceful curves. Each "eye," measuring from 5 to 30 mm., is usually composed of a single crystal individual which, however, is very rarely solid

**Jour. Roy. Soc. W.A.*, Vol. VII., p. 71.

†Since this paper was read Prof. E. W. Skeats has drawn my attention to the analysis of a staurolite schist from Kanton Tessin, Switzerland, showing SiO_2 , 66.97; Al_2O_3 , 14.22.

staurolite. Commonly it is an intergrowth in almost any proportions of staurolite and granular quartz, the former mineral impressing a Fontainebleau structure on the eye. As much as 70 or 80 per cent. of quartz may be thus enveloped, though usually not more than 30 or 40. The colour of the eye varies with the proportion of quartz, usually it ranges from chesnut brown to tawny (Ridgway 11'm to 13'i). A typical light brown "eye" which was sectioned was found to consist of about 46 or 47 per cent. staurolite, and the same of quartz, whilst the balance was made up of granular iron ore, muscovite, biotite, and chlorite, with pleochroic haloes in the last, surrounding some small and some relatively large zircon crystals. In only one instance were crystal faces indistinctly seen, though the strong cleavage parallel to (010) is readily observed in most cases.

Genesis of the Chittering Kyanite and Staurolite.

Too little is known of the petrology and structural geology of the Chittering Valley to be sure of the origin of the staurolite and kyanite observed there. It is to be noted in this connection that the staurolite rock at Wattle Flat occurs in at least one, possibly three, narrow bands, interbedded with garnetiferous gneiss and more normal gneiss, as well as with a siliceous kyanite schist. A microline granite only slightly gneissic is found within at most a few miles on two sides of the Wattle Flat occurrence, and within at most a mile of the South Bindoon and Lower Chittering kyanite localities. Innumerable other rock outcrops are to be seen in every direction in this hilly country, but as yet have not been examined.

It would appear as if the whole of this area were occupied by a fluxion gneiss traversed by occasional epidiorite dykes, and that either certain portions were originally more highly foliated and showed greater differentiation on a small scale, due to a local relative poverty in alkalis and lime, or that shearing stresses have spent themselves on certain zones, without affecting the whole mass, and along these zones there has been a circulation of heated waters charged with active chemical agents. The latter theory would explain the presence of numerous lenticular quartz veins at all three localities, as well as the development of kyanite crystals in the heart of a quartz vein at Lower Chittering. The production of secondary mica from feldspar involves the solution and removal of two-thirds of the potash and silica in the original mineral. Were this common process intensified and part of the remaining alkali removed, kyanite or one of its congeners would be likely to result, and might be crystallised in part in situ, in part in cavities with the dissolved silica, resulting in a kyanite-bearing quartz vein.